Assessment of the Relationship Between Freshwater Inflow and Biological Indicators in Lavaca Bay

RFQ# 580-18-RFQ0068

Paul Montagna

Texas A&M University Corpus Christi | HARTE Research Institute for Gulf of Mexico Studies

Joe Trungale

Trungale Engineering & Science

Team Qualifications

Paul Montagna

- Endowed Chair, HRI
- Professor, PENS
- Working on TX inflow since 1986
- Consulting on inflow in CA, FL, Morocco, South Korea
- SAC member 2004, 2006, 2008-2013
- 69 peer-reviewed publications, 78 reports

Joe Trungale

- Principal, Trungale Engineering & Science
- Working on TX inflow since 1998
- Trinity-San Jacinto and Colorado-Lavaca BBEST member
- Water Availability (WAM) and Estuarine Circulation/Salinity (TxBLEND) Modeling

Existing Lavaca Bay Publications

1. Montagna, P.A., X. Hu, T.A. Palmer, and M. Wetz. 2018. Effect of hydrological variability on the biogeochemistry of estuaries across a regional climatic gradient. *Limnology and Oceanography* 63:2465-2478.
2. Wetz, M.S., E.K. Cira, B. Sterba-Boatwright, P.A. Montagna, T.A. Palmer, and K.C. Hayes. 2017. Exceptionally high organic nitrogen concentrations in a semi-arid South Texas estuary susceptible to brown tide blooms. *Estuarine, Coastal and Shelf Science* 188: 27-37.
3. Van Diggelen, A.D. and P.A. Montagna. 2016. Is salinity variability a benthic disturbance in estuaries? *Estuaries and Coasts* 39:967-980.
4. Paudel, B., P.A. Montagna and L. Adams. 2015. Variations in the release of silicate and orthophosphate along a salinity gradient: Do sediment composition and physical forcing have roles? *Estuarine, Coastal and Shelf Science* 157: 42-50.
5. Hu, X., J. Beseres-Pollack, M.R. McCutcheon, P.A. Montagna, and Z. Ouyang. 2015. Long-term alkalinity decrease and acidification of estuaries in Northwestern Gulf of Mexico. *Environmental Science & Technology* 49: 3401-3409.
6. Palmer, T.A. and P.A. Montagna. 2015. Impacts of droughts and low flows on estuarine water quality and benthic fauna. *Hydrobiologia* 753:111–129.
7. Hu, X., J. Beseres-Pollack, M.R. McCutcheon, P.A. Montagna, and Z. Ouyang. 2015. Long-term alkalinity decrease and acidification of estuaries in Northwestern Gulf of Mexico. *Environmental Science & Technology* 49: 3401-3409.
8. Kim, H.-C., S. Son, P. Montagna, B. Spiering, and J. Nam. 2014. Linkage between freshwater inflow and primary productivity in Texas estuaries: downscaling effects of climate variability. *Journal of Coastal Research*, Special Issue No. 68: 65-73.
9. Paudel, B. and P.A. Montagna. 2014. Modeling inorganic nutrient distributions among hydrologic gradients using multivariate approaches. *Ecological Informatics* 24:35-46.
10. Kim, H.-C. and P.A. Montagna. 2012. Effects of climate-driven freshwater inflow variability on macrobenthic secondary production in Texas lagoonal estuaries: A modeling study. *Ecological Modelling* 235– 236: 67– 80.
11. Montagna, P.A., J. Brenner, J. Gibeaut, and S. Morehead. 2011. Coastal Impacts. In: Schmandt, J., G.R. North, and J. Clarkson (eds.), *The Impact of Global Warming on Texas, second edition*. University of Texas Press, Austin, Texas, pp. 96-123.
12. Montagna, P., G. Ward and B. Vaughan. 2011. The importance and problem of freshwater inflows to Texas estuaries. In: *Water Policy in Texas: Responding to the Rise of Scarcity*, R.C. Griffin (ed.), The RFF Press, Washington, D.C. pp. 107-127.
13. Pollack, J.B., T.A. Palmer, and P.A. Montagna. 2011. Long-term trends in the response of benthic macrofauna to climate variability in the Lavaca-Colorado Estuary, Texas. *Marine Ecology Progress Series* 436: 67–80.
14. Palmer, T.A., P.A. Montagna, J.B. Pollack, R.D. Kalke and H.R. DeYoe. 2011. The role of freshwater inflow in lagoons, rivers, and bays. *Hydrobiologia* 667: 49-67.
15. Montagna, P.A. and J. Li. 2010. Effect of Freshwater Inflow on Nutrient Loading and Macrobenthos Secondary Production in Texas Lagoons. In: *Coastal Lagoons: Critical Habitats of Environmental Change*, M. J. Kennish and H. W. Paerl (eds.), CRC Press, Taylor & Francis Group, Boca Raton, FL, pp. 513-539.
16. Kim, H.-C. and P.A. Montagna. 2009. Implications of Colorado River freshwater inflow to benthic ecosystem dynamics: a modeling study. *Estuarine, Coastal and Shelf Science* 83:491-504.
17. Pollack, J.B., J.W. Kinsey, and P.A. Montagna. 2009. Freshwater Inflow Biotic Index (FIBI) for the Lavaca-Colorado Estuary, Texas. *Environmental Bioindicators* 4:153-169.
18. Shank, G.C., K. Nelson, and P.A. Montagna. 2009. Importance of CDOM distribution and photoreactivity in a shallow Texas estuary. *Estuaries and Coasts* 32:661-677.
19. Montagna, P.A., T.A. Palmer, R.D. Kalke, and A. Gossmann. 2008. Suitability of using a limited number of sampling stations to represent benthic habitats in Lavaca-Colorado Estuary, Texas. *Environmental Bioindicators* 3: 156 – 171.
20. Montagna, P. A., J. C. Gibeaut and J.W. Tunnell Jr.. 2007. South Texas climate 2100: Coastal impacts. In: J. Norwine and K. John (eds.), *South Texas Climate 2100: Problems and Prospects, Impacts and Implications.* CREST-RESSACA. Texas A&M University-Kingsville, Kingsville, Texas. Chapter 3, pp. 57-77.
21. Russell, M.J. and P.A. Montagna. 2007. Spatial and temporal variability and drivers of net ecosystem metabolism in Western Gulf of Mexico Estuaries. *Estuaries and Coasts* 30: 137-153.
22. Russell, M.J, P.A. Montagna, and R.D. Kalke. 2006. The effect of freshwater inflow on net ecosystem metabolism in Lavaca Bay, Texas. *Estuarine, Coastal and Shelf Science* 68:231-244.
23. Montagna, P.A. and R.D. Kalke. 1995. Ecology of infaunal Mollusca in south Texas estuaries. *American Malacological Bulletin* 11:163-175.
24. Kalke, R. and P.A. Montagna. 1991. The effect on freshwater inflow on macrobenthos in the Lavaca River delta and upper Lavaca Bay, Texas. *Contributions in Marine Science* 32:49-77.

Project Purpose

- Provide an understanding of the relationships between freshwater inflow and habitat in Lavaca Bay based on long-term monitoring data
- Provide information for consideration by the BBASC and the TCEQ during future rulemaking related to environmental flow standards for Lavaca Bay

- Fulfills Stakeholder needs: CLBBASC Work Plan
  – Number 12
    - Priority 1 calls for intense literature review
    - Priority 6 calls for analysis of commercially important species
    - Priority 8 calls for evaluation of achievement of MBHE recommendations
  – Number 14 calls for improvement of hydrodynamic models by ensuring input data sets are correct

Tasks and Subtasks

1. Obtain data
    a. Create analyzable data
2. Statistical analyses
3. Interpretation
4. Meetings
5. Deliverables

Tasks	Quarters				
	10/2018 - 12/2018	1/2019 - 3/2019	4/2019 - 6/2019	7/2019 - 9/2019	10/2019 - 12/2019
1	X	X			
1a	X	X	X	X	
2	X	X	X	X	
3			X	X	X
4		X			X
5	X	X	X	X	X

Tasks and Subtasks

1. Obtain data
   a. Create analyzable data
2. Statistical analyses
3. Interpretation
4. Meetings
5. Deliverables

2.1. Bioindicator identification
2.2. Condition identification
2.3. Inflow identification
2.4. Time series, autocorrelation, and confounding factors identification
2.5. Event identification
2.6. Linking inflow events and communities

Proposed Methodology

Freshwater Inflow
- Quantity
  - Timing
  - Frequency
  - Duration
  - Extent
- Quality
- Tidal connections

Estuarine Conditions
- Salinity
- Sediment
- Dissolved material
- Particulate material

Estuarine Resources
- Integrity
  - Species composition
  - Abundance
  - Biomass
  - Diversity
- Function
  - Primary production
  - Secondary production
  - Nutrient recycling
- Sustainability
  - Habitats
  - Valued resources
  - Ecosystem services

Sources: Alber (2002) *Estuaries*; Palmer et al., *Hydrobiologia*, **667**:49-67 (2011), Montagna et al. (2013)

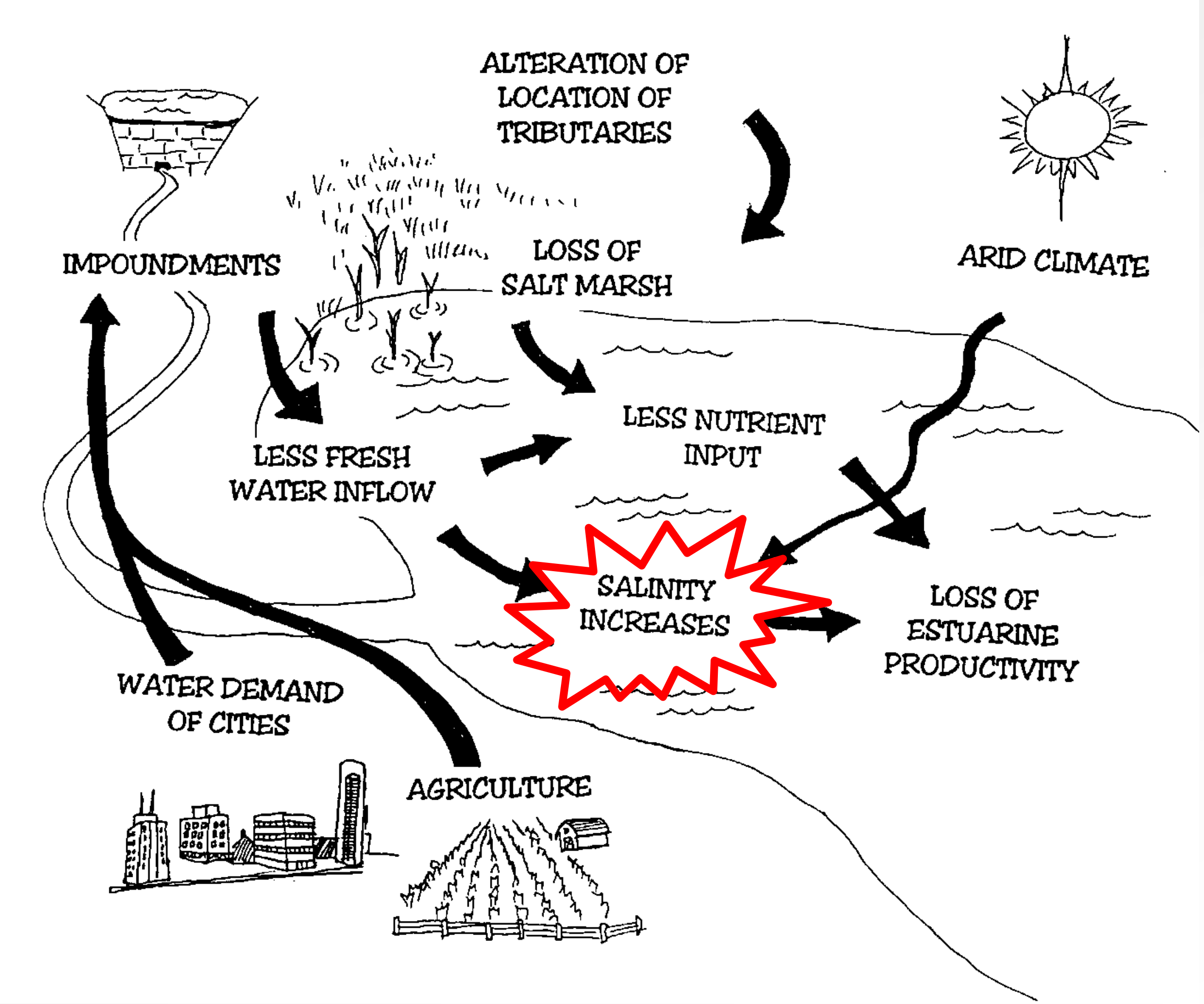
- Inflow Has Indirect Effects: “Domino Theory”
- We will link estuary conditions to benthic response using multivariate analysis and non-linear models to find optimal salinity ranges

Proposed Methodology

- Bioindicator identification
  - Already know bivalves are sensitive to salinity change
  - Already know biodiversity is the best indicator of ecological integrity
- Condition identification
  - Water quality to define habitat zones
- Inflow identification
  - Flows needed to maintain designed salinity
- Evaluation of existing standards
  - Attainment frequencies
  - Effects on habitat zones

Altered Freshwater Inflow Changes Estuaries

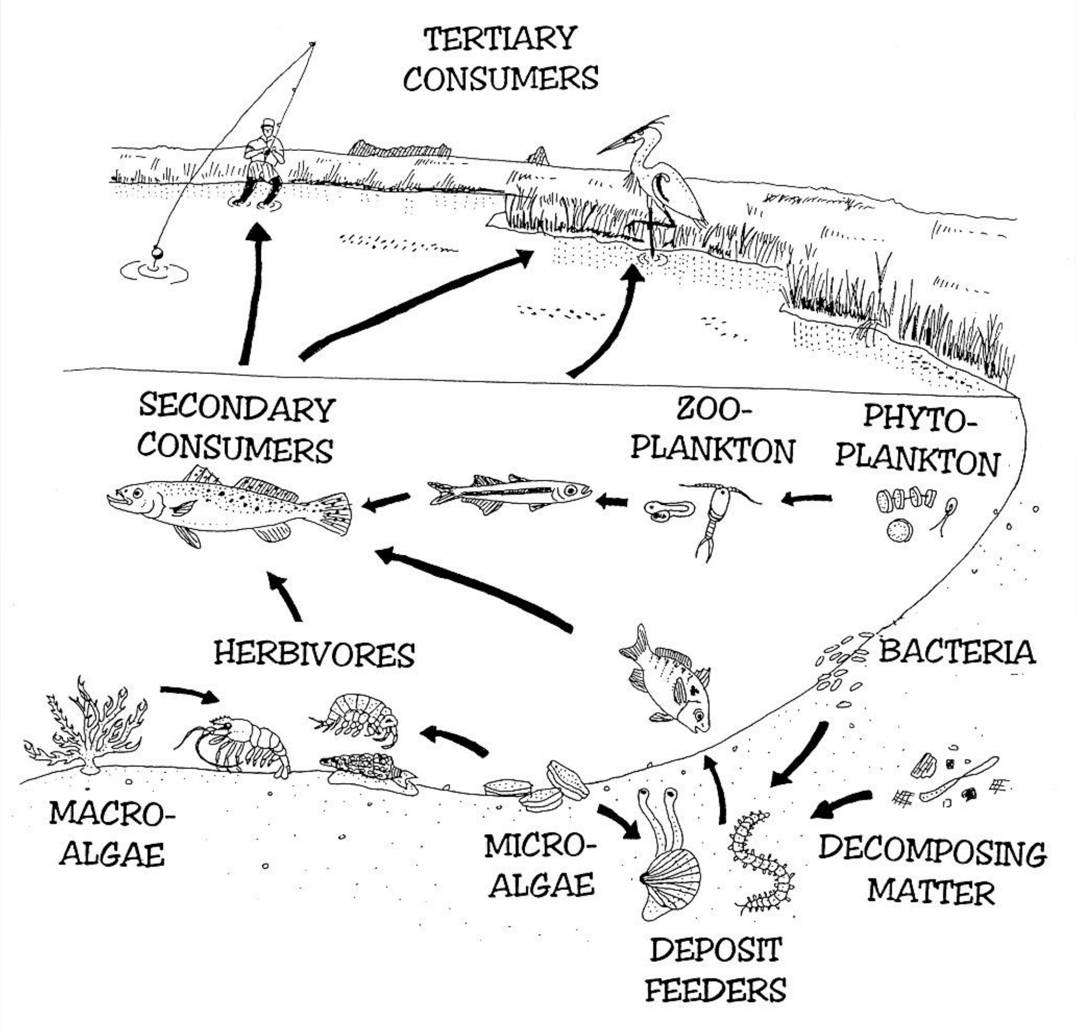
- Changes:
  - Hydrology
  - Nutrients
  - Sediments
  - Salinity
- Alters:
  - Habitat
  - Biodiversity
  - Productivity
  - Ecosystem Services



Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Ecological Indicators That Work

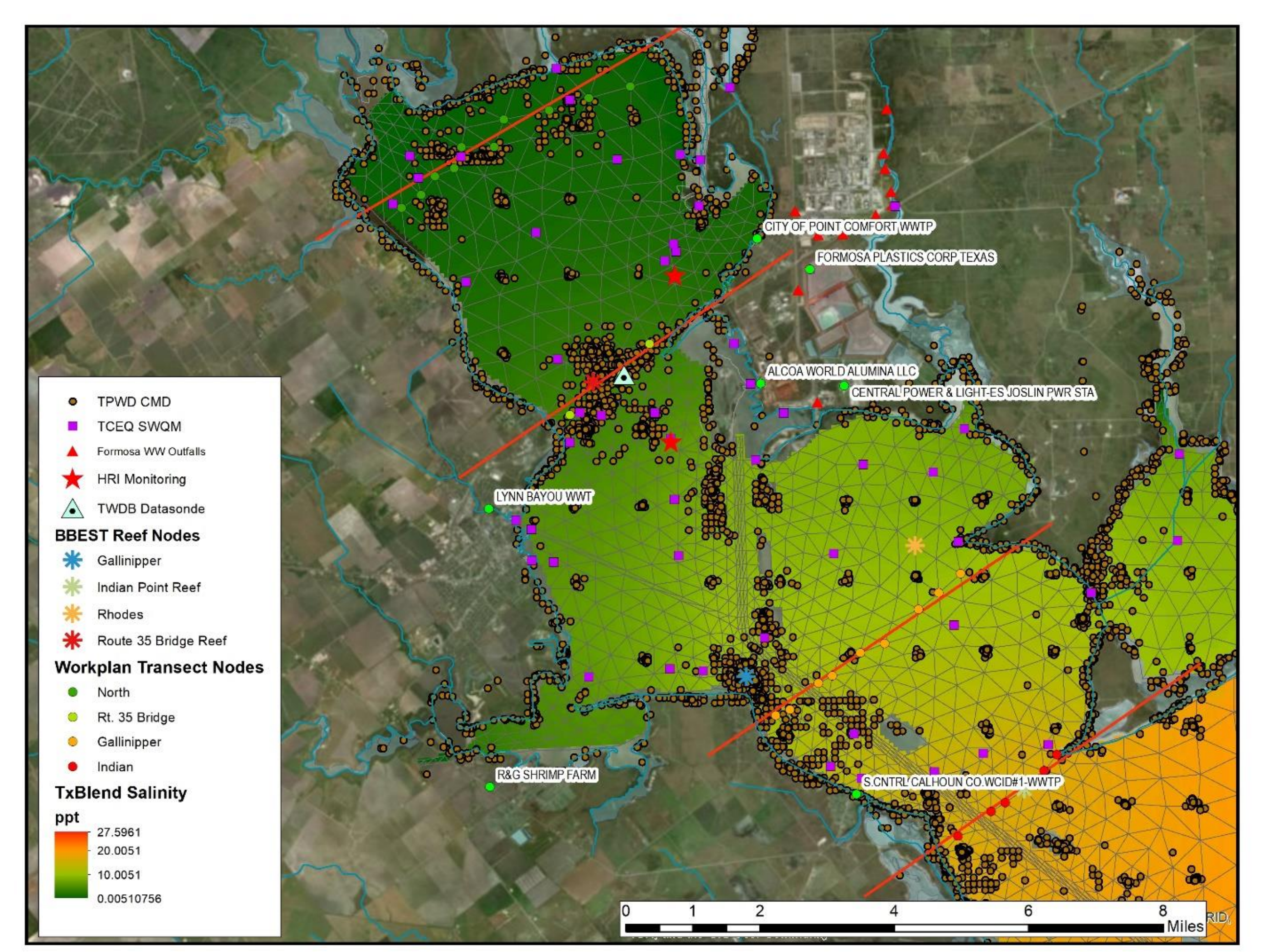
- Function
  - Ecological processes
    - Production, trophic links, reproduction
- Integrity
  - Community structure and biodiversity
    - Benthos, nekton, plankton
- Sustainability
  - Ecosystem services
    - Supports human life
    - Habitats, Habitats, Habitats



Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Long-Term Data Sets

- TCEQ – Water quality
- TPWD – Fisheries, epibenthos, oysters
- HRI – Nutrients, salinity, DO, Chl, sediments, macroinfauna
- Formosa – Site specific on contaminants, infauna
- Alcoa, EPA, HRI – Mercury in sediments, and fish

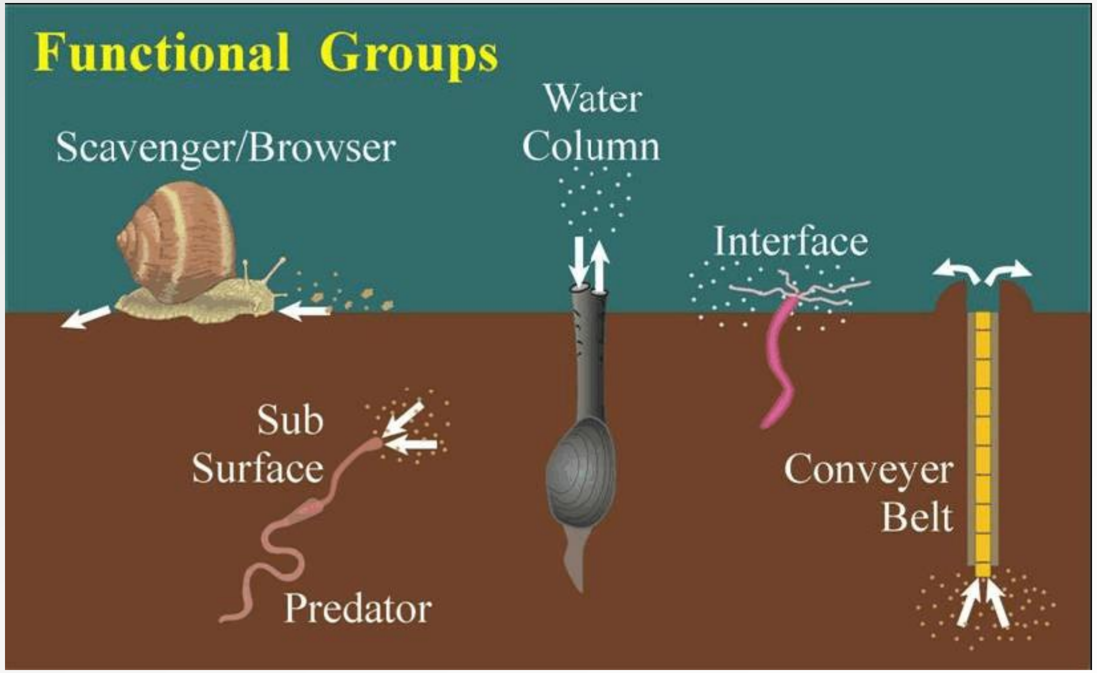


Bioindicators Used by BBEST's

Bay System	Indicator Species
Sabine Lake, 2009	Eastern oyster, Atlantic rangia, Blue crab juveniles, Olney bulrush, Intermediate marsh, Brackish marsh
Galveston Bay, 2009	Eastern oyster, Atlantic rangia, Dermo, Oyster drill, Wild celery, Gulf menhaden, blue catfish, Mantis shrimp, Pinfish
Brazos River, 2012	Salinity, Nutrients, Sediment supply
Lavaca and Matagorda Bays, 2011	Eastern oyster, Dermo, Oyster drill, brown shrimp, white shrimp, blue crab, Gulf menhaden and Atlantic croaker, Benthic infauna
Mission, Copano, Aransas, and San Antonio Bays, 2011	Eastern oyster, Atlantic rangia, brown rangia, white shrimp, Blue crab
Nueces, Corpus Christi, and Baffin Bays, 2011	Eastern oyster, Atlantic rangia, Smooth cordgrass, benthic infauna, blue crab, Atlantic croaker, nutrient cycling, sediment loading
Lower Laguna Madre, 2012	Seagrasses

Benthos are Excellent Bioindicators Because they Cannot Move

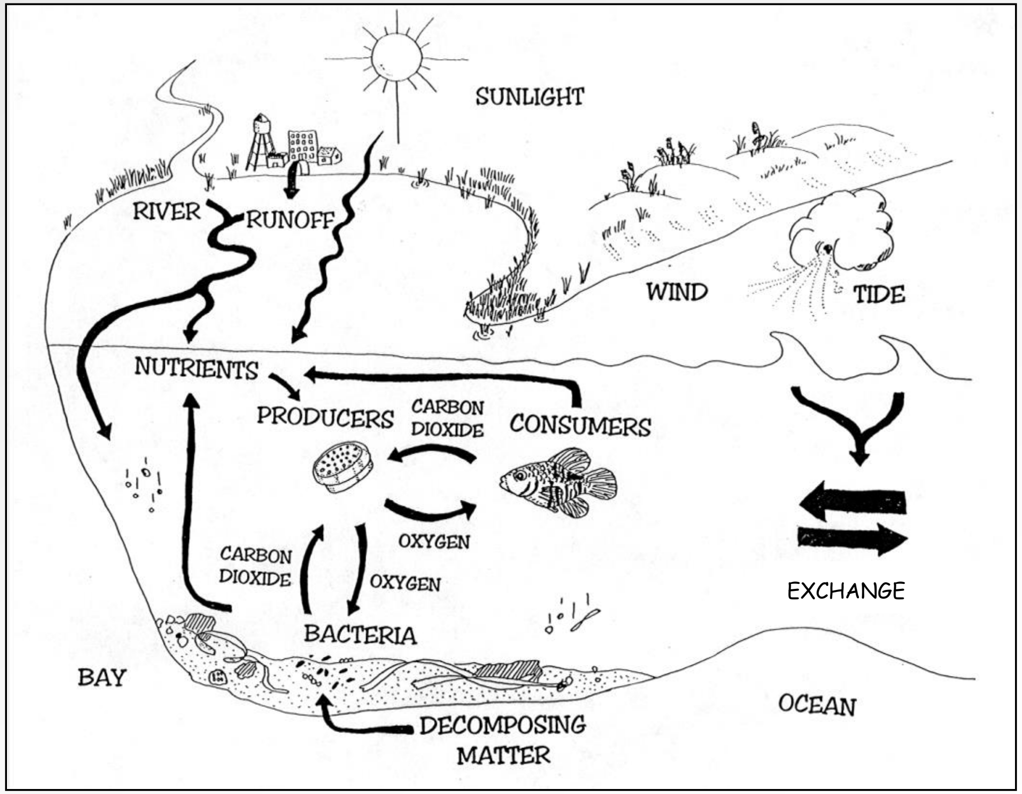
- Sessile
- Relatively long-lived
- Diverse
- Well known
- Respond to food from above



Source: Tenore, K.R. et al. (2006) *Journal of Experimental Marine Biology and Ecology* 330: 392-402.

Benthos are Excellent Bioindicators Because they are Integrators

- Sediments are the memory of the ecosystem
- Benthos affected first and most
- Thus, benthos are integrators
  - overlying water column is dynamic
  - benthos sample and integrate ephemeral events over long times scales

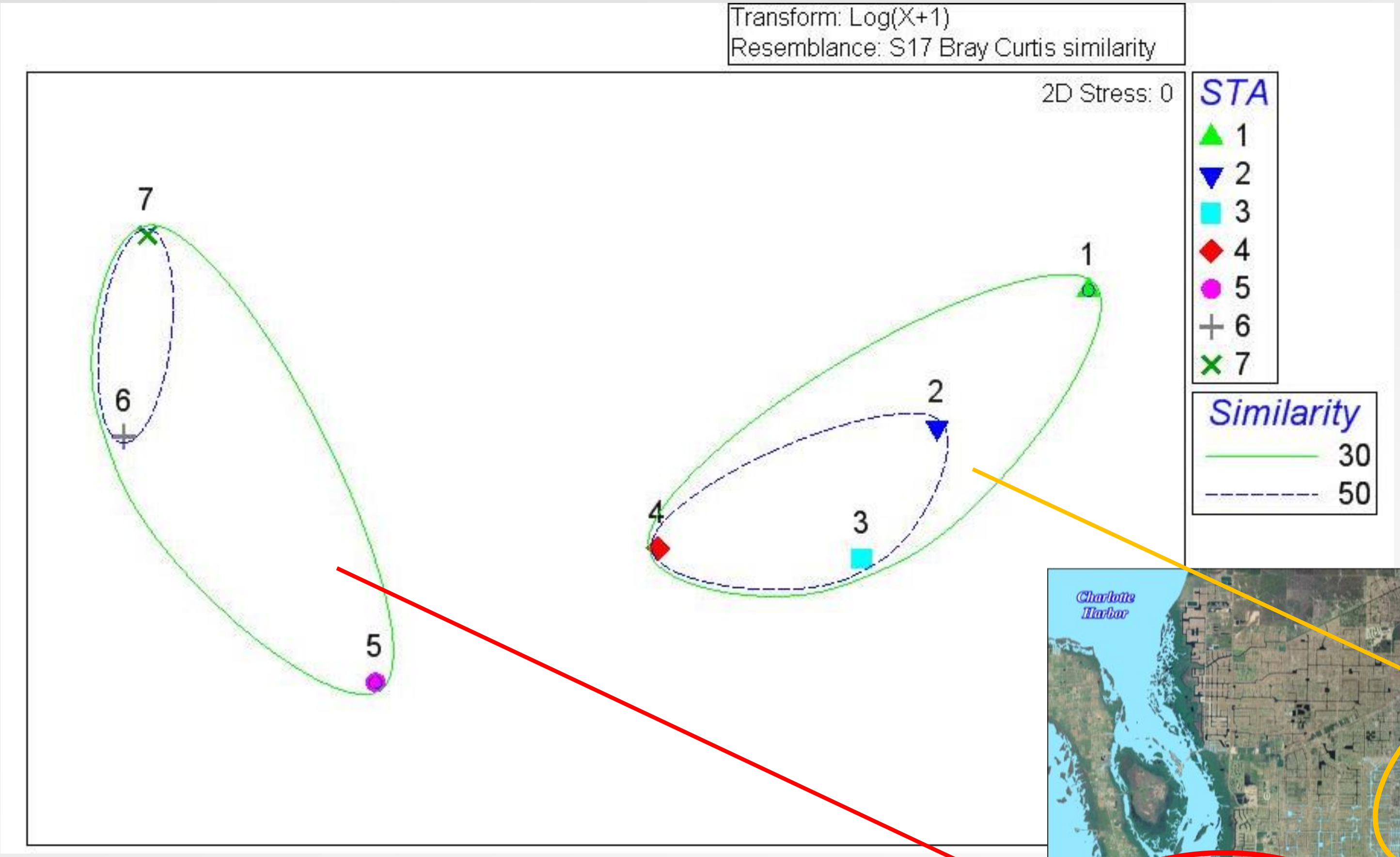


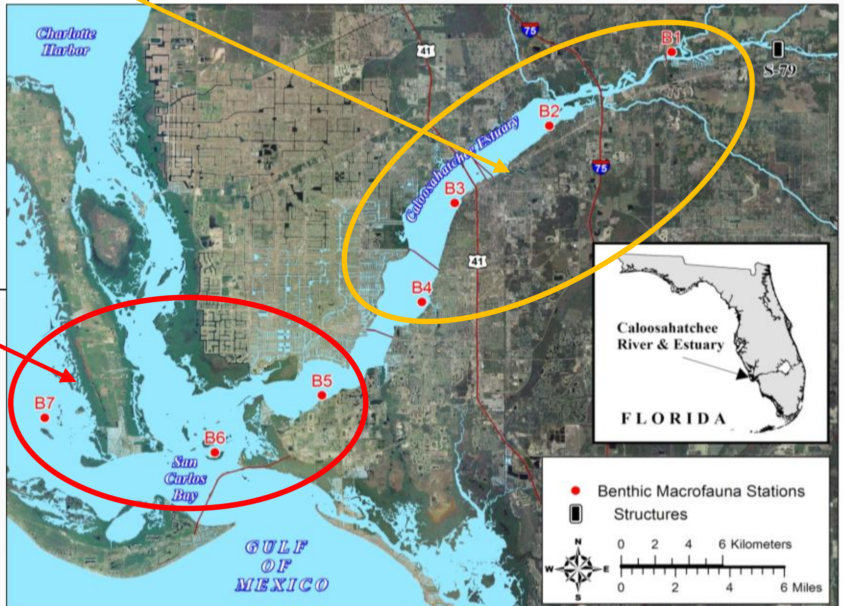
Source: Montagna et al. 1996, CCBNEP #8
http://cbbep.org/publications/virtuallibrary/ccbnep08.pdf

Examples of Methodological Approach

- Caloosahatchee River (SFWMD)
- Existing Lavaca and Matagorda Bays studies

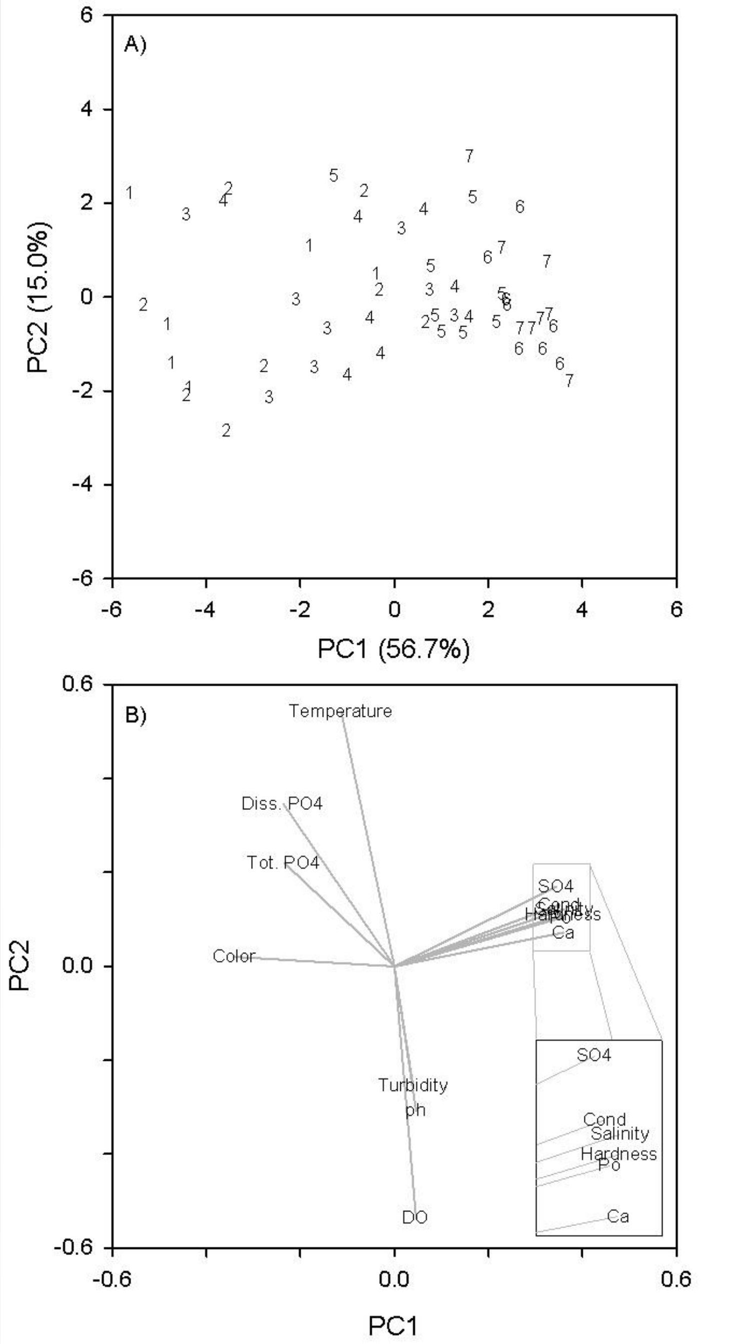
Caloosahatchee Estuary - Bioindicators





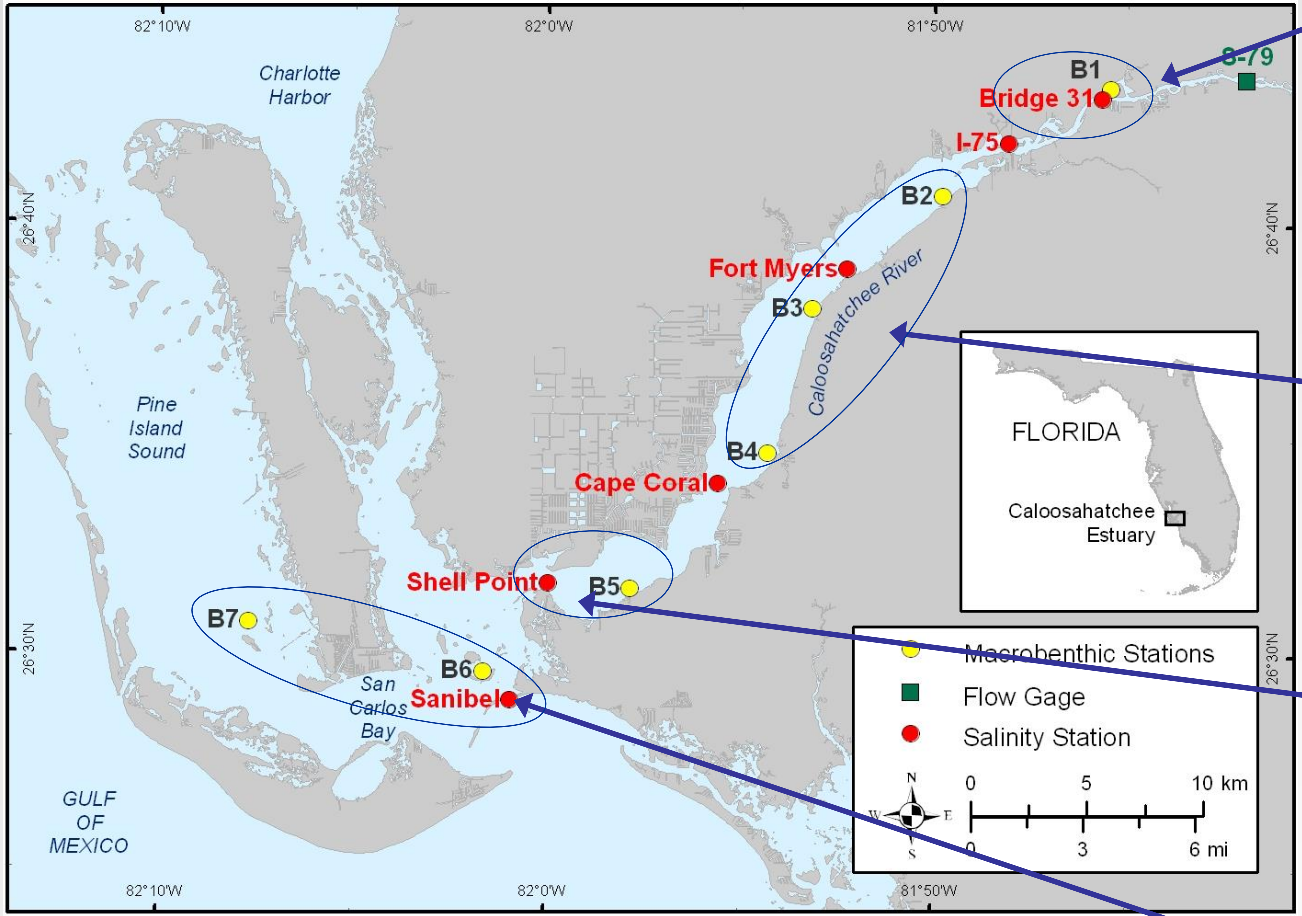
Looks like there are two communities based on salinity zones with break around 15 ppt

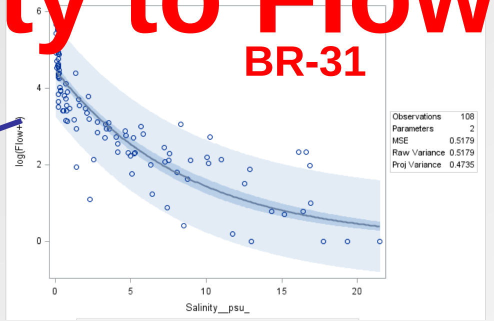
Caloosahatchee - Water Quality Conditions

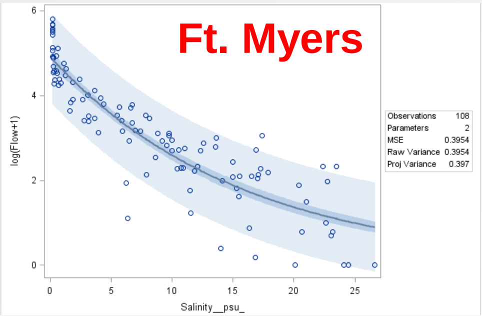


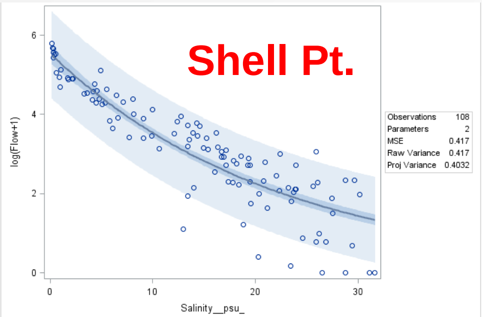
- Principal Components Analysis
  - Top: Station scores indicate FWI gradient
    - Mean for each station ± SE where 1=upstream to 7=downstream
    - Break at station 4 (±0)
  - Bottom: Vector loads
    - PC1 is an “inflow index”
    - PC2 is seasonal effects

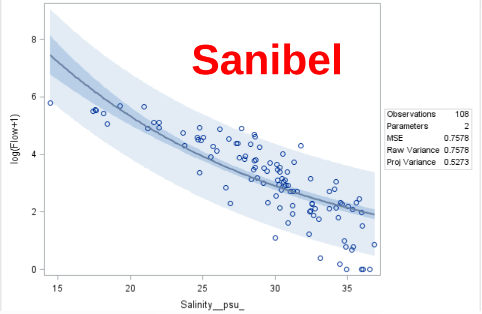
Caloosahatchee - Linking Salinity to Flow







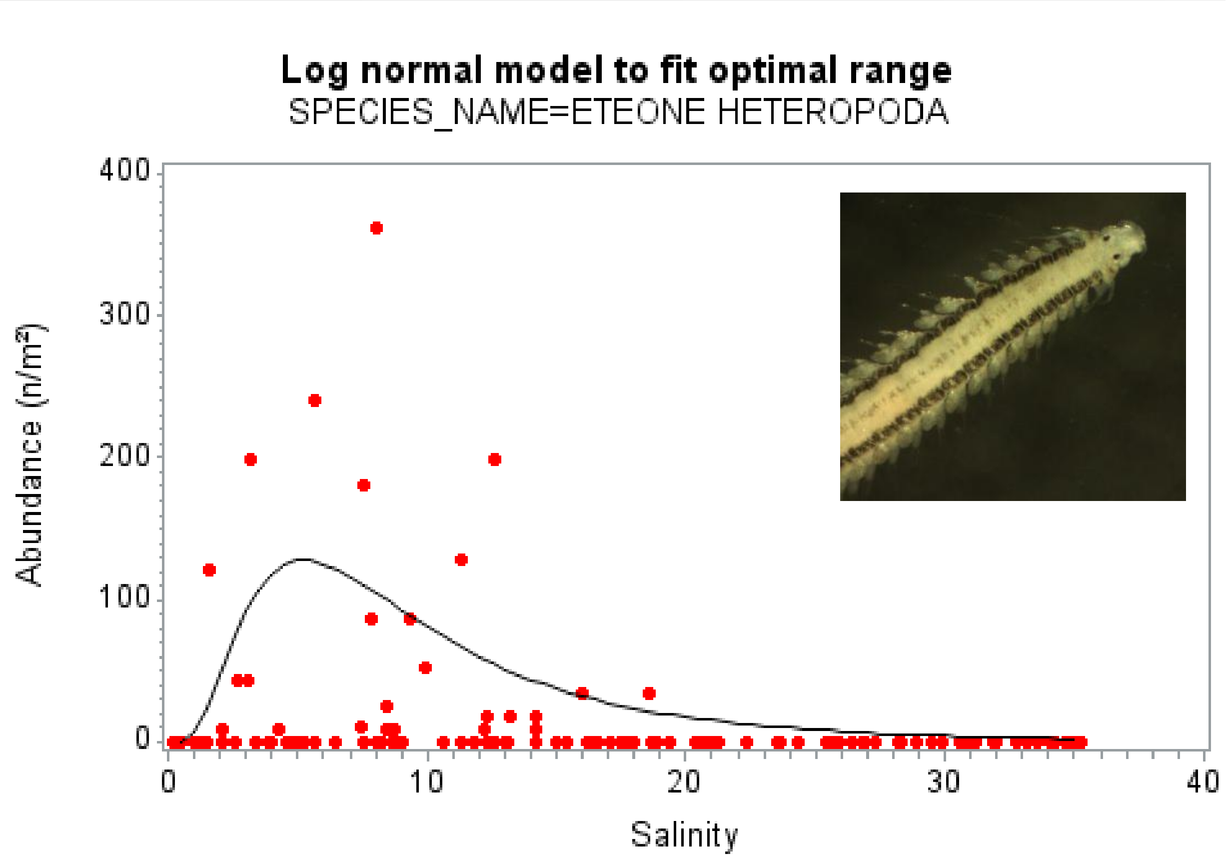


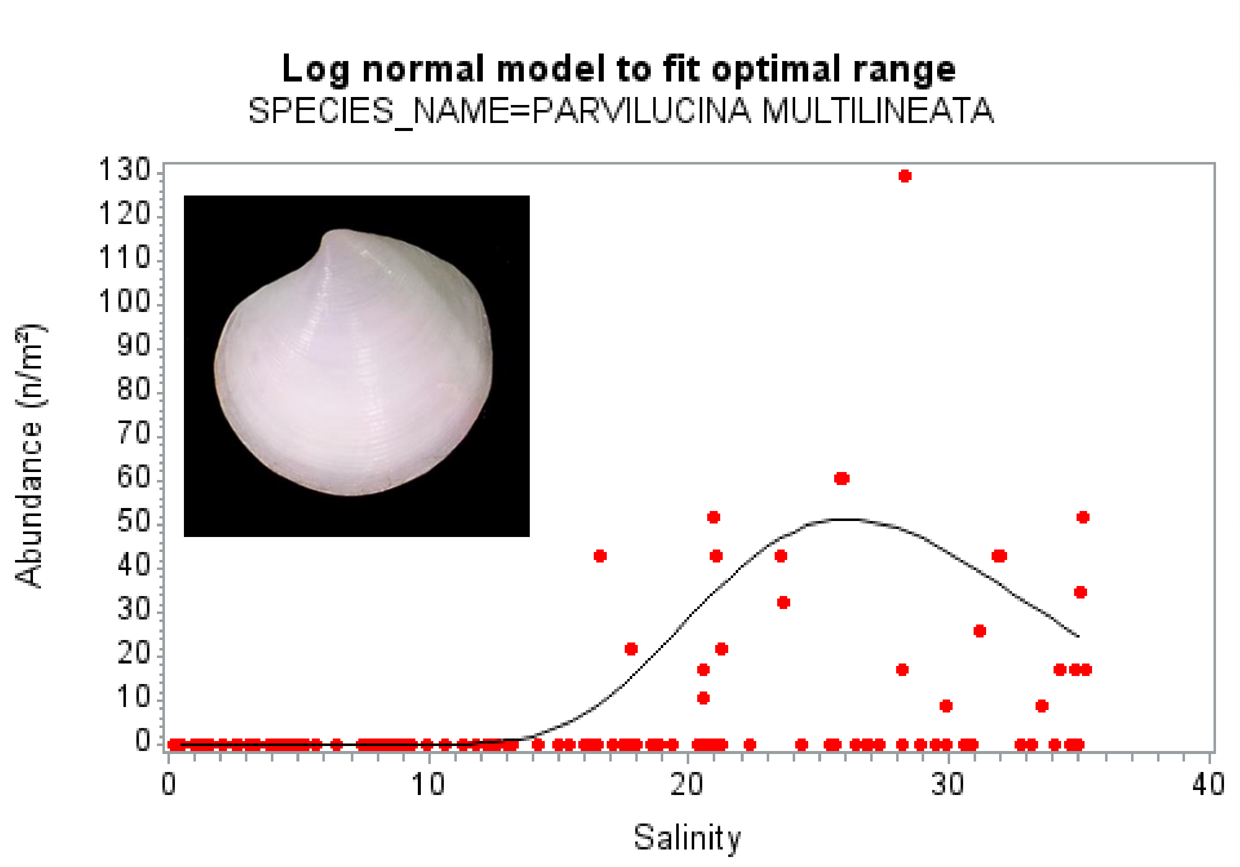


To predict flow for a salinity:

$$\log(Q + 1) = ae^{-bS}$$

Refining Flow Recommendations With Bioindicator Species





Caloosahatchee - Flow Requirements

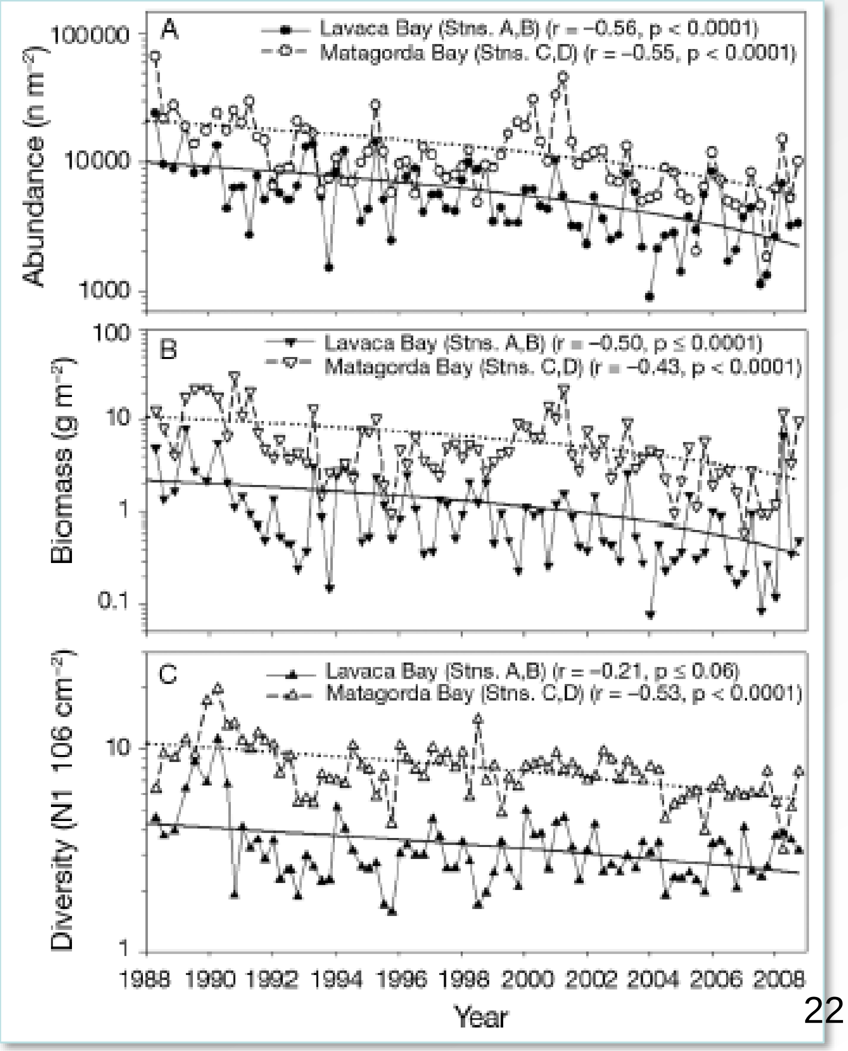
Period	Salinity Statistic	Zone	Salinity	Corresponding Flow (cfs)		
				Estimate	90% high Conf. Interval	90% low Conf. Interval
Dry	Lower Quartile	1	0.2	2749	2333	3236
		2	2.6	2253	2052	2464
		3	15.1	554	581	526
		4	28.0	905	874	825
	Median	1	1.2	1690	1548	1836
		2	7.1	767	781	749
		3	19.8	307	336	281
		4	32.5	398	422	340
	Upper Quartile	1	4.2	536	573	500
		2	12.5	286	316	259
		3	24.9	180	204	160
		4	34.7	279	307	233
Wet	Lower Quartile	1	0.2	2749	2333	3236
		2	0.2	4465	3743	5322
		3	7.9	1688	1603	1768
		4	21.0	5367	3992	6034
	Median	1	0.2	2749	2333	3236
		2	0.2	4465	3743	5322
		3	9.9	1190	1169	1205
		4	26.2	1345	1233	1274
	Upper Quartile	1	0.2	2699	2297	3167
		2	3.1	1955	1809	2102
		3	13.9	651	674	626
		4	30.5	558	570	488

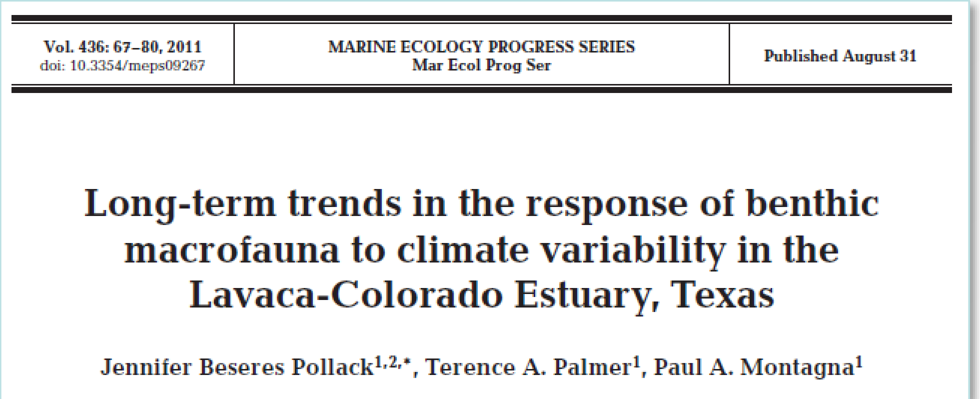
The Lavaca-Colorado Estuary is Complex

- Four sources of FW
- Two major sources
- Inflow dominates Lavaca Bay

There is a Long-term Decline in Benthos

- In 2011 we discovered that benthic macrofauna were declining dramatically (> 2 orders of magnitude) over 20 years in the Lavaca-Colorado Estuary, Texas



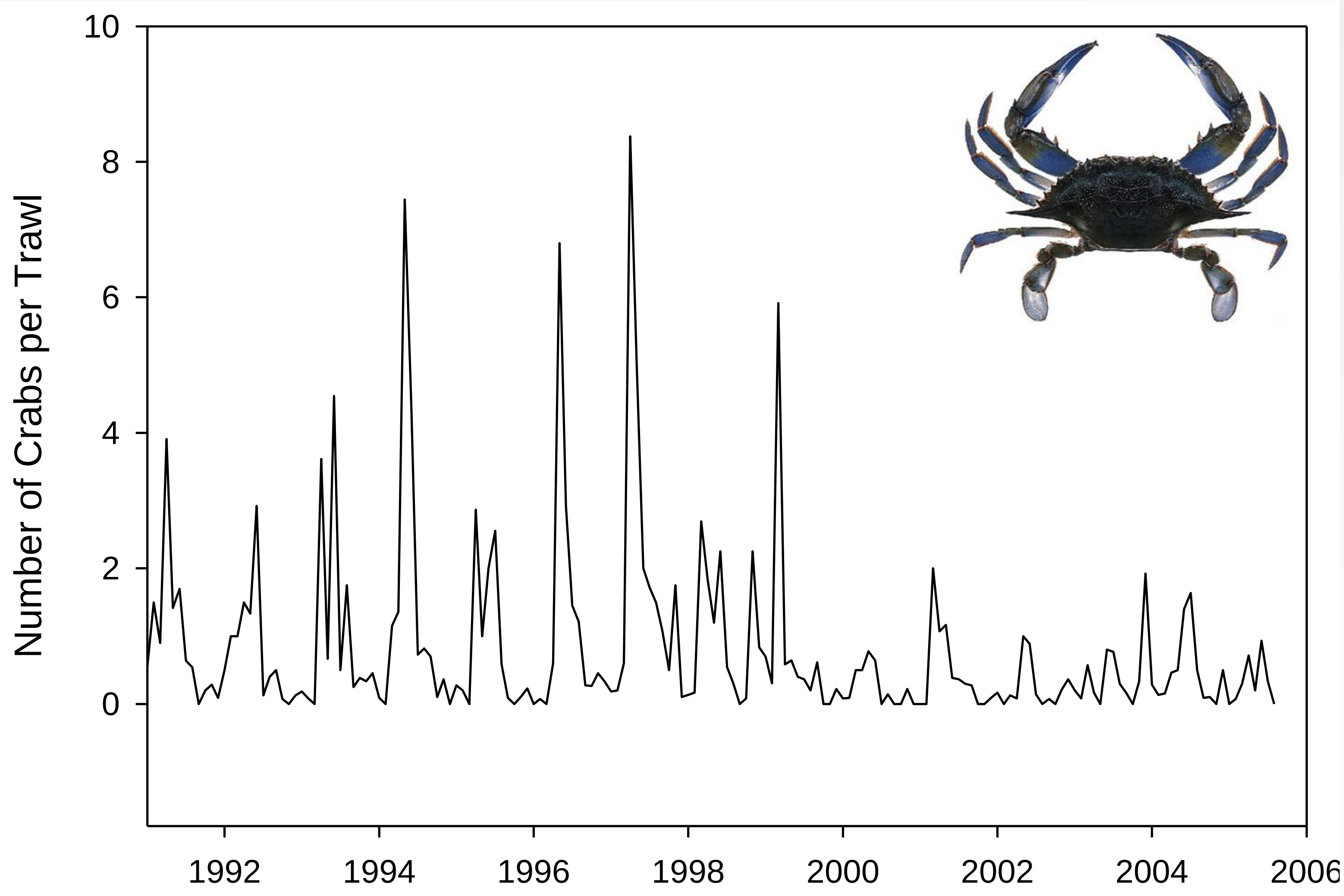


Vol. 436: 67–80, 2011
doi: 10.3354/meps09267
MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser
Published August 31

Long-term trends in the response of benthic macrofauna to climate variability in the Lavaca-Colorado Estuary, Texas

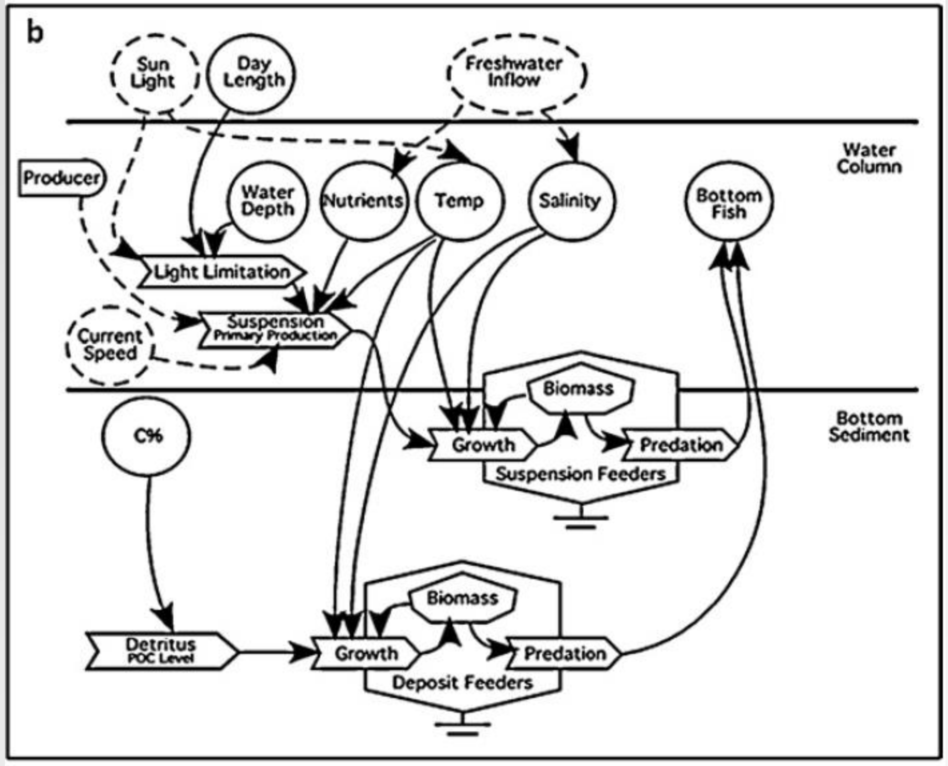
Jennifer Beseres Pollack[1,2,*], Terence A. Palmer[1], Paul A. Montagna[1]

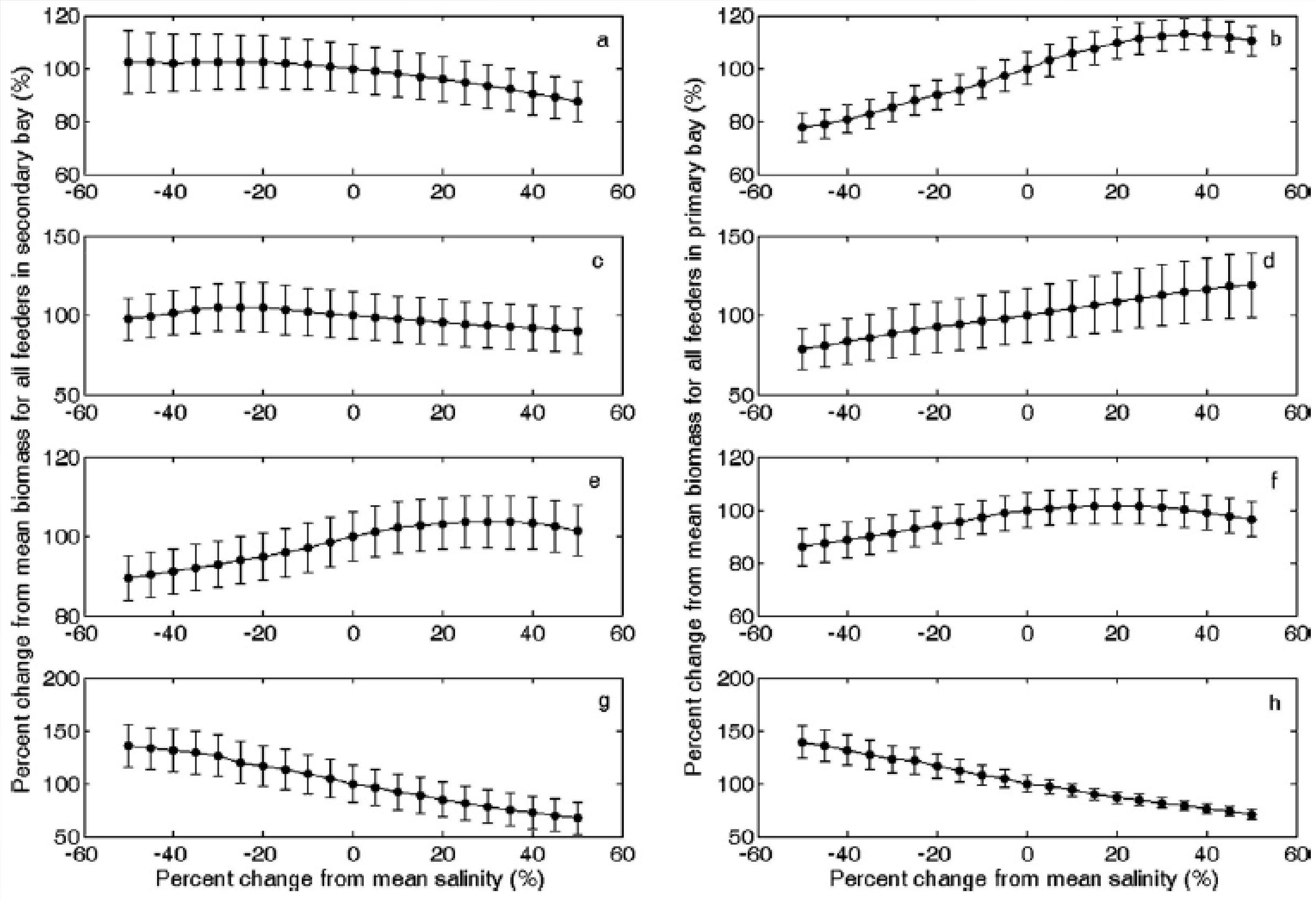
Blue Crab Declining Also



Source: Kim & Montagna (2009) Estuarine, Coastal and Shelf Science 83:491–504

Energetic Modeling Shows Salinity is the Driver





Already Developed a FWI Biotic Index

Environmental Bioindicators, 4:153–169, 2009

ISSN: 1555-5275 print/ 1555-5267 online
DOI: 10.1080/15555270902986831

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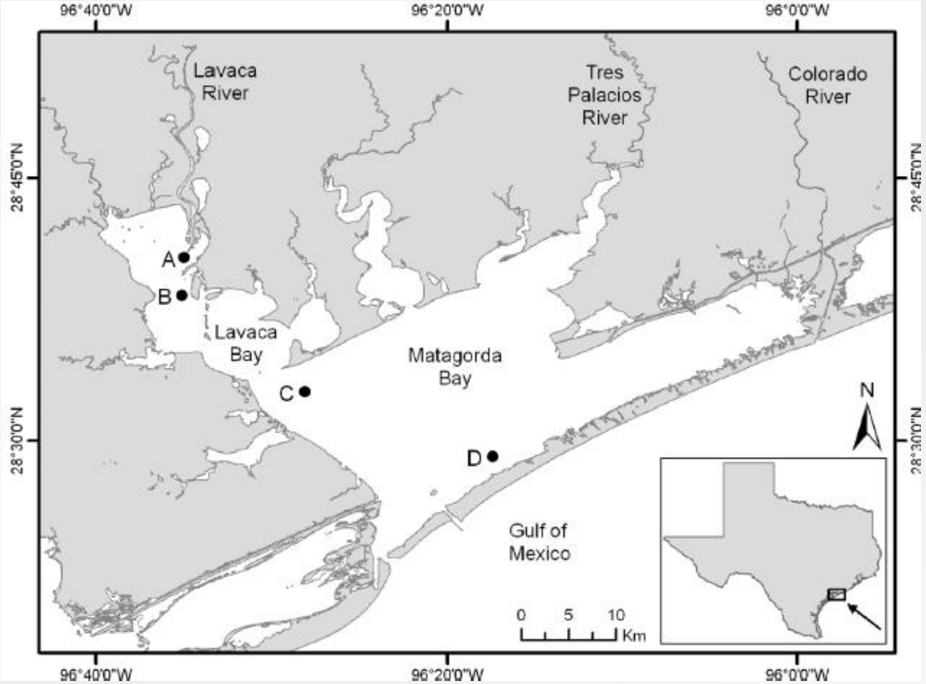
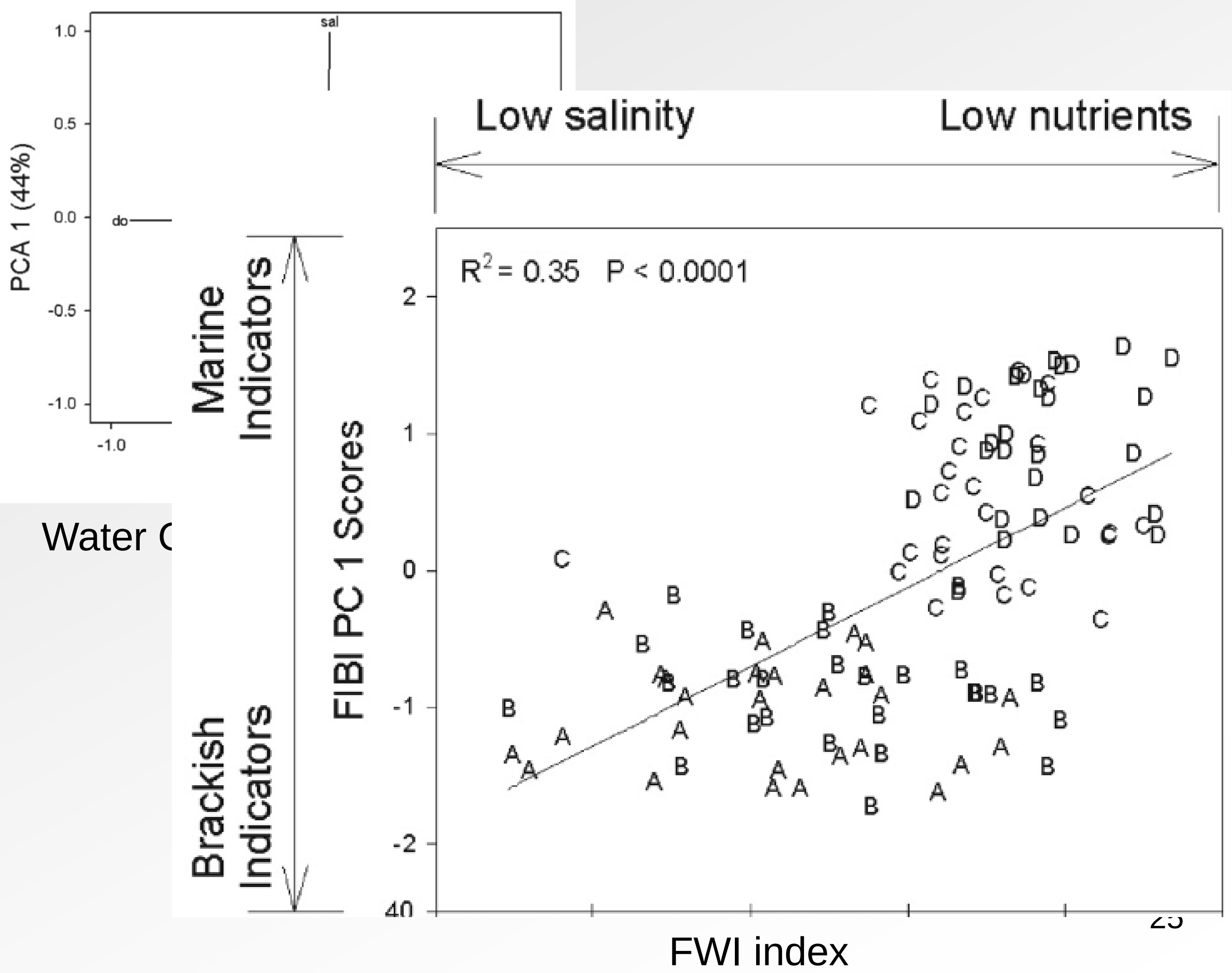
Freshwater Inflow Biotic Index (FIBI) for the Lavaca-Colorado Estuary, Texas

JENNIFER BESERES POLLACK,[1] JULIE W. KINSEY,[2] AND PAUL A. MONTAGNA[1]



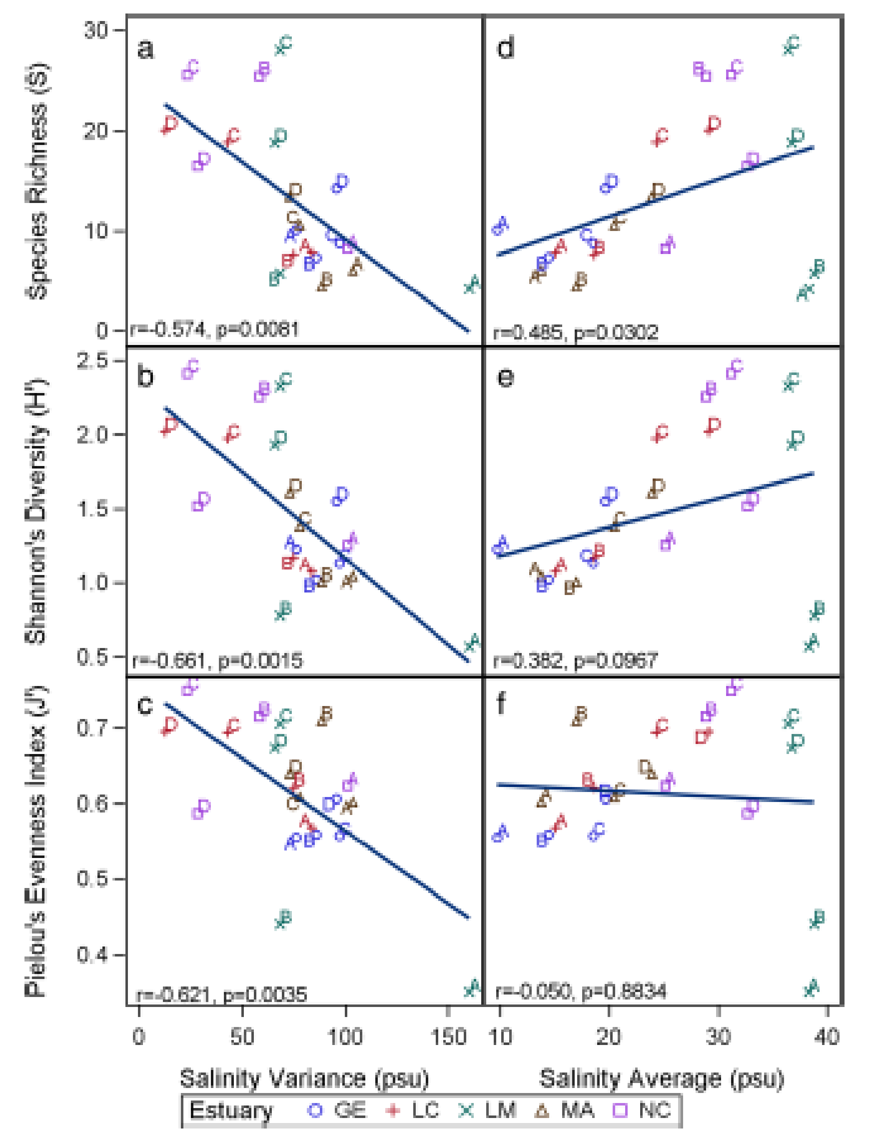


Proved The Driver is Salinity Variability

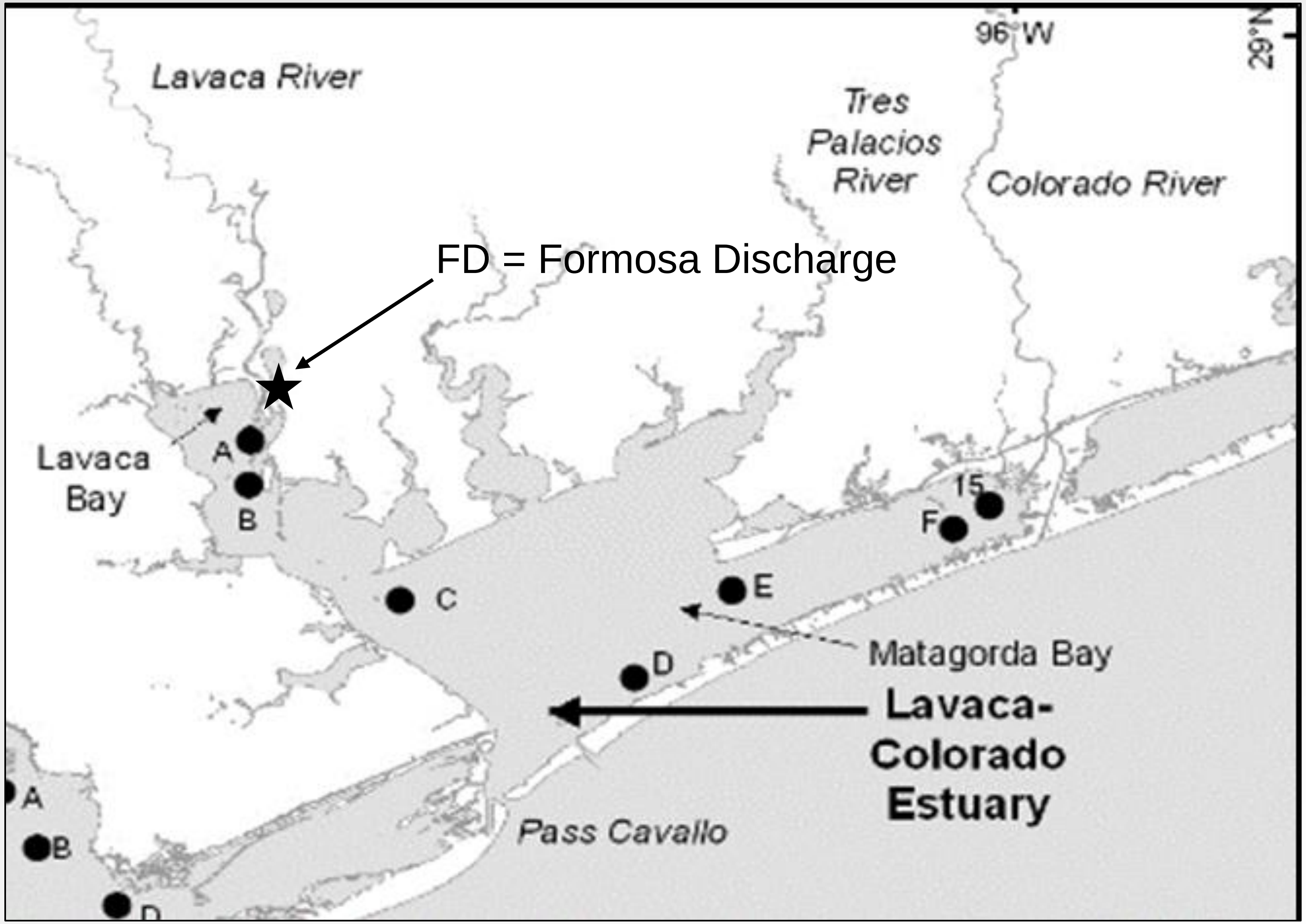
Estuaries and Coasts (2016) 39:967–980
DOI 10.1007/s12237-015-0058-9

Is Salinity Variability a Benthic Disturbance in Estuaries?

Amanda D. Van Diggelen[1,2] · Paul A. Montagna[1]

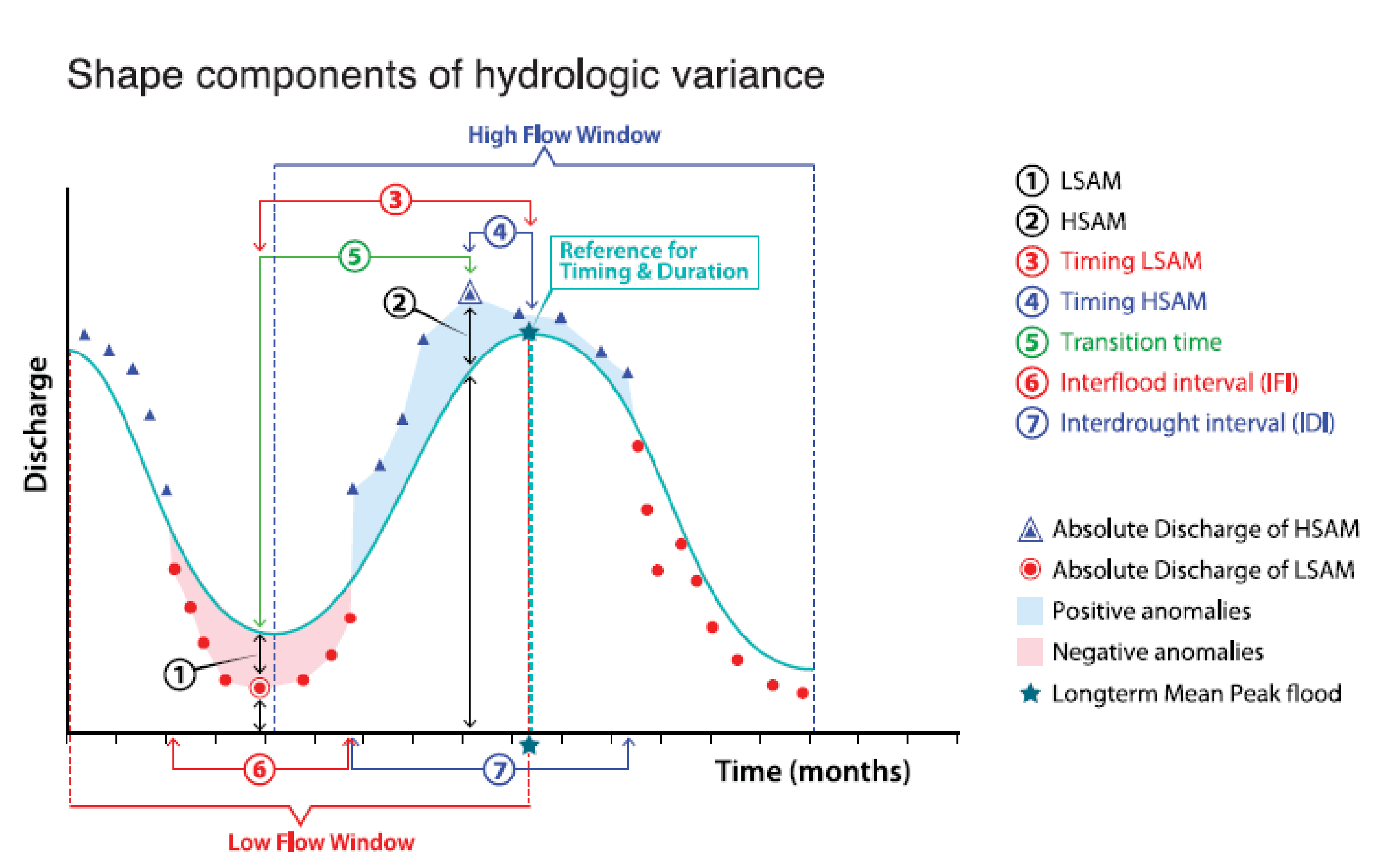


We Actually Have a Lot More Data



Time Series Approaches

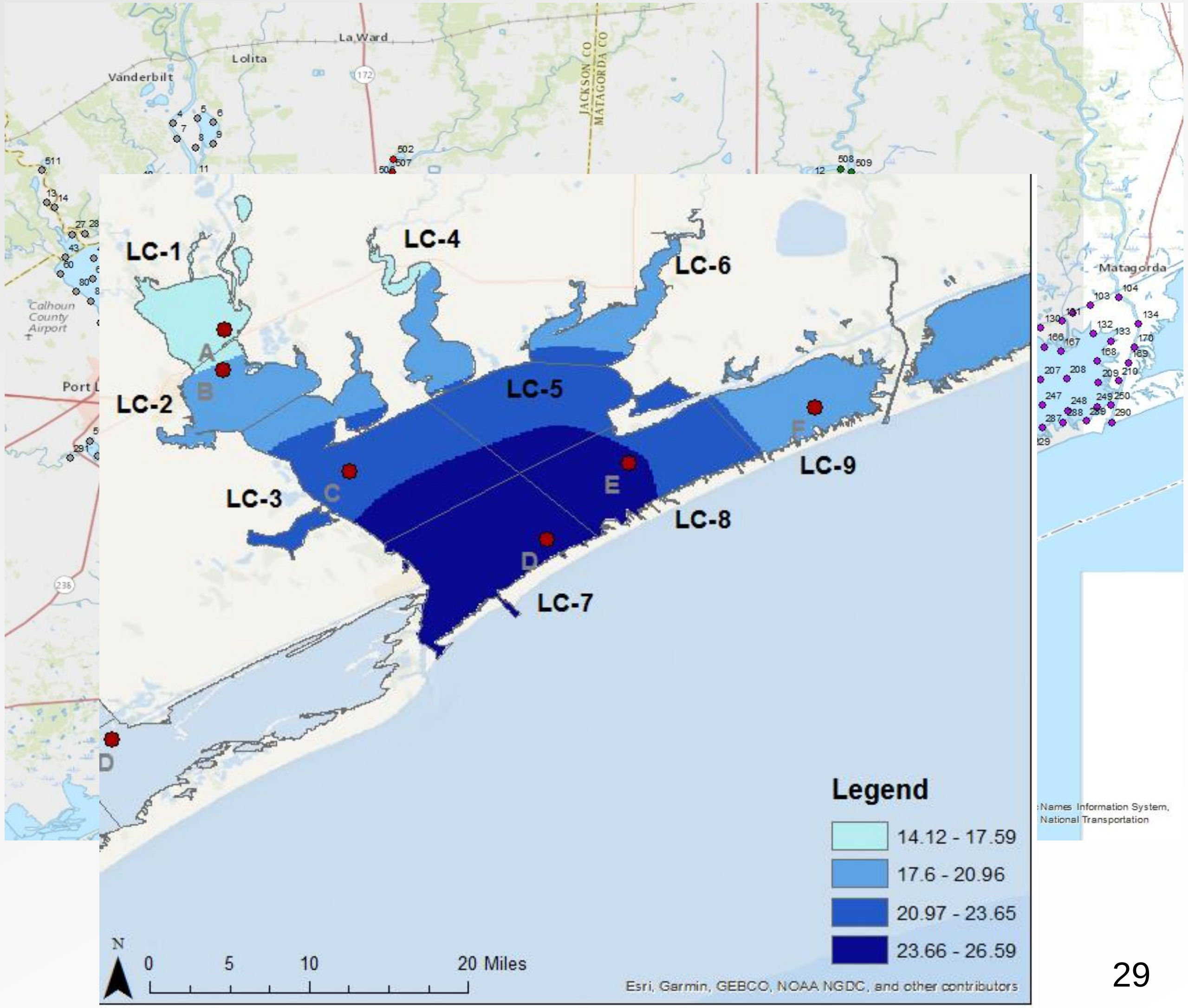
- Multivariate Autoregressive State Space (MARSS) to define the inflow regime (frequency, timing, magnitude, duration)
- Can compare interactions between species
- Examine role of multiple factors that can drive biological response
- Enables integration of data across trophic levels (infauna, epibenthos, fish)



Source: Sabo et al. (2017) Designing river flows to improve food security in the Lower Mekong Basin. *Science* 358

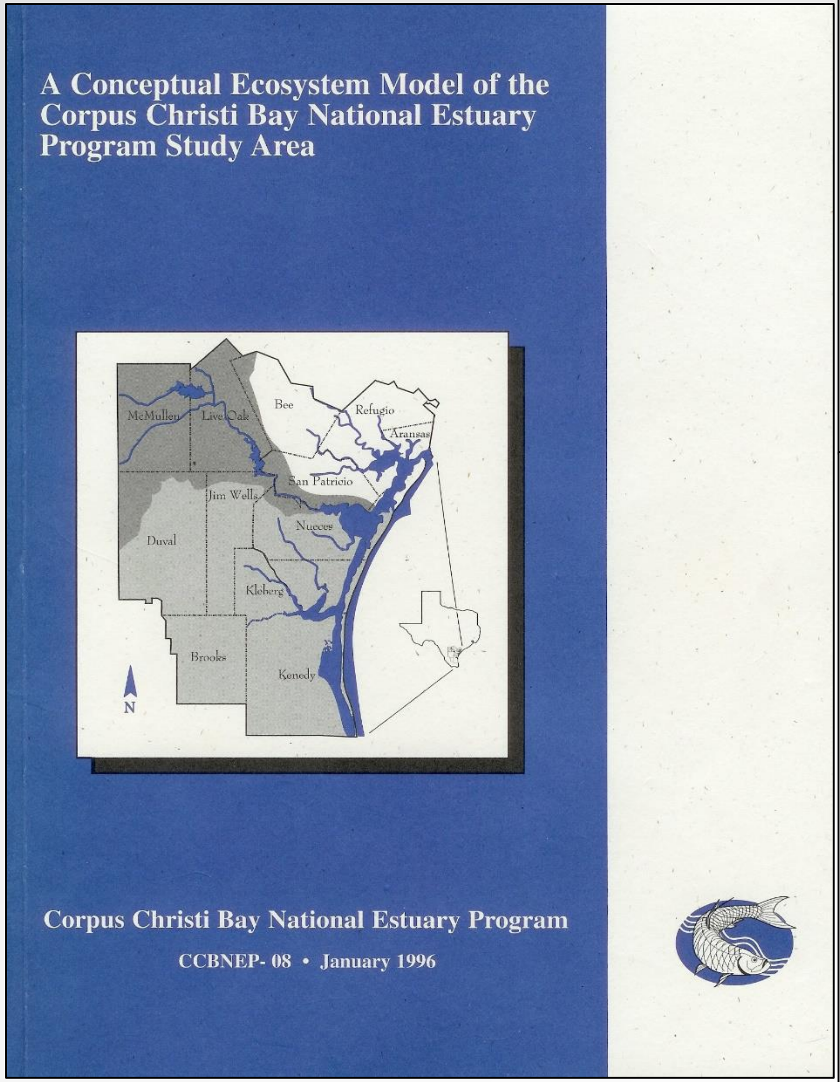
TPWD Data is Problematic

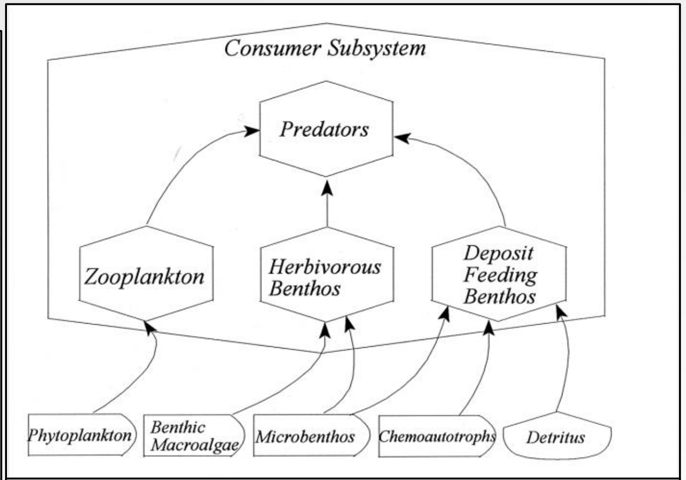
- TPWD manages fisheries by bay system
  - Set up hundreds of equidistant stations
  - Selects 10 randomly each month
- But our questions focus on within-bay dynamics along salinity gradients
  - Solution is to aggregate stations into segments

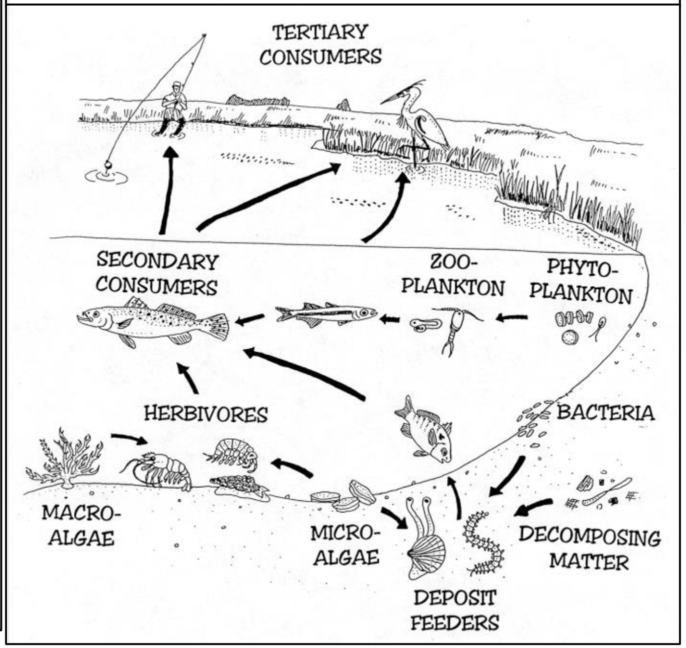


Communication Strategy

- Problem is not lack of information
- Problem is technical jargon!
- Solution is pairing illustrations with technical descriptions







Summary

- Demonstrated a sustained record of freshwater inflow studies at the highest technical levels since 1986
- Have created many of the methods for analyzing bioindicators of freshwater inflow effects
- Have performed similar studies in other States
- Demonstrated in depth knowledge of Lavaca Bay
- Have one of only four long-term data sets, but the only one specifically designed to identify inflow effects
- Solid plan for obtaining and analyzing data, computing inflow requirements, communicating with Stakeholders


Questions?
11.6.2002
10 km